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Enclosed herewith for filing is a patent application, as follows:

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Title: Two-Dimensional Scatter Plot Technique For Defect Inspection

- ☒ Return Receipt Postcard
☒ This Transmittal Letter (in duplicate)
3 page(s) Declaration For Patent Application and Power of Attorney
10 page(s) Specification (not including claims)
2 page(s) Claims
1 page Abstract
10 Sheet(s) of Drawings
1 page(s) Recordation Form Cover Sheet (in duplicate)
1 page(s) Assignment
☒ Other: 2 pages Appendix A

CLAIMS AS FILED (fees computed under §1.9(f))

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Independent Claims	3	-3 =	0	x	\$78	=	\$ 0.00
<input type="checkbox"/> Application contains one or more multiple dependent claims (\$260 total fee)						\$	0.00

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TWO-DIMENSIONAL SCATTER PLOT TECHNIQUE FOR DEFECT INSPECTION

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Background of the Invention

1. Field of the Invention

20

This invention generally relates to digital image
processing and, more particularly, to systems and
methods for detecting defects in a semiconductor device
using image comparison techniques.

25

2. Description of the Related Art

Image comparison techniques are used to detect
defects in a semiconductor wafer. Typically, a test
30 image is acquired and then compared to a reference
image. A defect-detection algorithm is then used to
detect variations between the images and to determine
whether such variations are real defects. In the so-
called random-logic inspection mode, an image of a
35 first die is acquired and then compared to the image of
a second die in the same wafer. Array-inspection mode

is similarly performed except that a section of a die is compared to another section in the same die having an identical structure. Array-inspection mode is used, for example, in testing devices with repeating structures such as memory cells. In lieu of comparing images from a wafer being tested, defects may also be detected by comparing an acquired test image with a known good image from a database.

Fig. 1 illustrates a defect-detection method in the prior art. A test image and a reference image of the wafer feature being analyzed are acquired from different sections of the wafer using, for example, conventional electron-beam imaging techniques (step 110). Each image comprises a plurality of pixels, with each pixel being defined by its location within the image and its intensity or gray level. The use of gray levels in image processing is known in the art and is described in R. C. Gonzales and R. E. Woods, "Digital Image Processing," Addison-Wesley (1992), e.g. pages 6-7, which is incorporated herein by reference in its entirety. The two images are then aligned pixel-by-pixel such that each feature in the test image matches up with the corresponding feature in the reference image (step 120). A difference image is then generated by subtracting the gray levels of the two images (step 130). Because matching pixels with identical gray levels will be subtracted out, the difference image represents pixel gray level variations between the reference image and the test image. The gray level of each pixel in the difference image is scaled, normalized, and then plotted in a one dimensional histogram such as histogram 200 shown in Fig. 2 (step 140). Histogram 200 plots the number of pixels in the difference image having a specific gray level. For instance, histogram 200 indicates that there are 20,000

pixels in the difference image having a gray level of 50.

5 A pixel from the test image can be different from
a corresponding pixel in the reference image even if
there are no defects in the two images. Intensity
variations can be caused by, for example, differences
in the physical layer structures, noise in the image
acquisition electronics and signal paths, and varying
10 noise modulation level within a single image across
different gray levels. Thus, pixels in the difference
image do not necessarily indicate that a defect exists.
To differentiate real defects from false or "nuisance"
defects, each pixel in the difference image is compared
15 to a threshold window (Fig. 1, step 150). Pixels with
a gray level outside the threshold window are declared
defects. For example, if the threshold window is ± 50
and a pixel in the difference image has a gray level of
60 (i.e. the gray levels of the test and reference
20 images differ by 60 units), a defect event is declared
(Fig. 1, step 160). The defect event is then verified
by an operator to ensure that the die is indeed
defective before the die is discarded in subsequent
processing.

25

Finding the optimum threshold value for a given
test image is an important but imprecise task. The
threshold value must be chosen such that real defects
are detected while differentiating nuisance defects.
30 The narrower the threshold value, the more nuisance
defects will be declared. Nuisance defects adversely
affect production throughput because each defect event
must be checked and verified. On the other hand,
widening the threshold window will reduce nuisance
35 defect events at the expense of letting real defects go
undetected. Thus, a method for evaluating the

effectiveness of a threshold or thresholding scheme is highly desirable.

Summary

5

The invention provides for a method and associated apparatus for relating a test image with a reference image. In an embodiment of the invention, the test and reference images are aligned. A two-dimensional scatter plot is then created by plotting the gray level of a test image pixel against the gray level of a corresponding reference image pixel for each aligned pixel location. The invention is applicable to electron-beam, bright-field, dark-field, laser, and atomic-force microscopy ("AFM") inspection systems.

Brief Description of the Drawings

Fig. 1 shows a defect detection method in the prior art.

Fig. 2 shows a one-dimensional histogram plot of gray levels.

Fig. 3 shows the steps of an embodiment of the present invention.

Figs. 4A-4c show an alignment step in accordance with the present invention.

Figs. 5A-5B show a two-dimensional scatter plot in accordance with the present invention.

Figs. 6-7 show a test image and a reference image, respectively, taken from a device wafer.

Figs. 8-9 show a two-dimensional scatter plot in accordance with the present invention.

Detailed Description

35

The present invention provides for a method and associated apparatus for relating the pixel of a test image with the corresponding pixel on a reference image. The invention can be used in determining the effectiveness of a threshold or thresholding scheme. The invention is also useful in other image processing applications such as those disclosed by the same inventor in the related co-pending U.S. Patent Application No. _____, filed _____, Attorney Docket No. M-7721, "Adaptive Mask Technique For Defect Inspection," which is incorporated herein by reference in its entirety. Other uses for the invention are in electron-beam, bright-field, dark-field, laser, and atomic-force microscopy ("AFM") inspection systems.

Fig. 3. illustrates the steps of an embodiment of the present invention. In step 310, a test image and a reference image of, for example, semiconductor structures are acquired using conventional image acquisition techniques. The images can also be acquired using the step-and-image acquisition system disclosed in commonly-owned US Patent Application Serial No. 09/226,967, "Detection of Defects In Patterned Substrates," filed January 8, 1999, which is incorporated herein by reference in its entirety.

In step 320, the test and reference images are aligned to match up corresponding pixels between the two images. A variety of alignment techniques can be used with the present invention including the technique disclosed in commonly-owned US Patent Application Serial No. 09/227,747, "Feature-Based Defect Detection," filed January 8, 1999, which is incorporated herein by reference in its entirety.

Step 320 is further illustrated in Figs. 4A-4C. Fig. 4A shows a test image 410 comprising pixels 411-416. Each pixel is defined by its gray level and its location on the image. As an example, pixel 413 is on
 5 location $i=10$ and $j=30$ (i.e. $(10,30)$). The gray level of pixel 413 is 50 for purposes of this illustration. Table 1 provides the coordinate location and gray level for each pixel of test image 410 while Table 2 provides the same information for pixels 421-426 of reference
 10 image 420 (Fig. 4B).

Table 1

Pixel	Location (i, j)	Gray Level
411	(10,10)	100
412	(10,20)	150
413	(10,30)	50
414	(20,30)	180
415	(20,20)	200
416	(20,10)	250

15

Table 2

Pixel	Location (i, j)	Gray Level
421	(10,10)	100
422	(10,20)	150
423	(10,30)	50
424	(20,30)	150
425	(20,20)	100
426	(20,10)	0

Fig. 4C graphically shows the alignment of test image 410 with reference image 420. Aligned pixel
 20 location 431 comprises the pixels 411 and 421, aligned

pixel location 432 comprises the pixels 412 and 422,
and so on.

Once the reference and test images are aligned,
5 the pixel-to-pixel correspondence between the test
image and the reference image is known. For each
aligned pixel location, the gray level of a pixel from
the test image is plotted against the gray level of the
corresponding pixel in the reference image (Fig. 3,
10 step 330). Using Fig. 4C as an example, the gray level
of pixel 411 is plotted against the gray level of pixel
421, the gray level of pixel 412 is plotted against the
gray level of pixel 422, and so on. Using step 330 for
locations 431-436 yields the data points shown in Table
15 3. The resulting two-dimensional scatter plot 500 is
shown in Fig. 5A.

Table 3

Location	Test Image Gray Level	Reference Image Gray Level
431	100	100
432	150	150
433	50	50
434	180	150
435	200	100
436	250	0

20

Table 3 shows that locations 434, 435, and 436
have varying gray levels and, thus, indicate the
presence of possible defects. Locations 431, 432, and
25 433 are free of defects because the test image and the
reference image have the same gray levels in said
locations. Scatter plot 500 (Fig. 5A) provides
information as to the presence of possible defects.

All aligned pixel locations with the same gray levels can be represented in scatter plot 500 by an imaginary line 501 (Fig. 5A). The slope of imaginary line 501 is +1 because it represents the aligned pixel locations wherein the gray level of the test image pixel is the same as the gray level of the corresponding pixel in the reference image. All aligned pixel locations with varying gray level values will lie away from imaginary line 501. The further a location is plotted away from line 501, the greater the deviation in gray levels, and the higher the chance that a defect exists in that location. In scatter plot 500, locations 434, 435, and 436 are not on imaginary line 501 and indicate the presence of possible defects.

Scatter plot 500 may be used to evaluate the effectiveness of a threshold or thresholding scheme. For example, a threshold window of ± 40 gray level units may be plotted and superimposed on scatter plot 500 as shown by lines 502 and 503 in Fig. 5B. Line 502 represents all aligned pixel locations wherein the gray level of the test image is greater than the gray level of the reference image by 40 units. Similarly, line 503 represents aligned pixel locations wherein the gray level of the reference image is greater than that of the test image by 40 units. Aligned pixel locations outside lines 502 and 503, such as locations 435 and 436, will be declared as defect events. In Fig. 5B, locations 431, 432, 433, and 434 will not trigger a defect event because said locations are within the threshold window. Different threshold windows can be plotted and superimposed on scatter plot 500 to determine which aligned pixel locations will be "captured" and declared as a defect event. Threshold windows may be generated using equations for shapes other than parallel lines. This capability to

visualize the extent of a threshold window is particularly useful to the skilled artisan in determining an appropriate threshold during test development.

5

A pseudo code for implementing an embodiment of the invention in computer software is shown below. In the pseudo code, the gray level values are plotted in a memory array variable ("Scatter"). Appendix A lists the source code of a function written in the C programming language. On page 2 of Appendix A, "hist2D8" creates a two-dimensional scatter plot in accordance with the present invention. The code would be executed by a computer or processor which is conventionally coupled to or a part of a defect inspection system. Of course, such a system would typically store this source code and the resulting plots in a computer-readable medium (memory).

```

20      /* PSEUDO CODE FOR CREATING A 2D SCATTER PLOT */
      Acquire Reference Image;
      Acquire Test Image;
      Align Test Image to Reference Image;
      Create a 256x256 Image named Scatter;
25      Initialize Scatter to 0;

      Do for i = 1 to NumRows
      {
30          Do for j = 1 to NumCols
          {
              p1 = Reference(i,j);
              p2 = Test(i,j);
              Scatter(p2,p1) = 1;
          }
35      }
      Plot Scatter as an Image;
      /* END OF PSEUDO CODE */

```

Figs. 6-9 pictorially summarize an embodiment of the present invention. Fig. 6 shows a test image 600 acquired conventionally from a wafer having a defect 601. A reference image 700 (Fig. 7) is similarly

acquired and then aligned (not shown) with test image 600. Two-dimensional scatter plot 800 is generated by plotting the gray level of the test image pixel against the gray level of the corresponding reference image pixel for each aligned location (Fig. 8). The scatter plot may be generated manually or by using a programmed computer. Aligned pixel locations are plotted as white dots in a dark background. In Fig. 8, line 801 defines the aligned pixel locations wherein the gray level of the test and reference image pixels are identical. For example, if test image 600 was identical to reference image 700, all points in scatter plot 800 would lie on line 801. To determine the extent of a threshold, the equation or parameters defining the threshold are plotted and shown in Fig. 9 as lines 901 and 902. Points outside lines 901 and 902 will be declared as defect events.

It is to be understood that the description given above is for purposes of illustration and is not intended to be limiting. Numerous variations are possible without deviating from the scope and spirit of the invention. The invention is set forth in the following claims.

25

WHAT IS CLAIMED IS:

1. In an image processing system, a method for relating a first image to a second image comprising the
5 acts of:
 - (a) aligning the first image with a second image; and,
 - (b) plotting the gray level of a pixel from the first image against the gray level of a corresponding pixel
10 from the second image for all aligned pixel locations.
2. The method of claim 1 further comprising the act of plotting a threshold window on a plot created in act
15 (b).
3. The method of claim 1 wherein a plot created in act (b) is stored in a memory array variable.
4. The method of claim 1 wherein a plot created in
20 act (b) is displayed on a video monitor.
5. A computer-readable medium storing a program for carrying out the method of claim 1.
- 25 6. A computer-readable medium comprising:

a plurality of memory locations storing data representing a first image and an associated second image, said first and second images each
30 having a plurality of pixels with each pixel being defined by a location coordinate and a gray level;
and,
an array comprising a plurality of memory locations storing data representing a plot of the gray
35 levels of pixels from the first image against the

gray levels of corresponding pixels from the second image.

7. A defect inspection system comprising:
- 5 (a) an image acquisition unit being operable to acquire a first image and an associated second image, the first and second images each having a plurality of pixels with each pixel being defined by a location coordinate and a gray level;
- 10 (b) a plurality of memory locations storing data representing the first image and the second image; and,
- (c) a processor being operable to plot the gray levels of pixels from the first image against the gray
- 15 levels of corresponding pixels from the second image.

TWO-DIMENSIONAL SCATTER PLOT TECHNIQUE FOR SEMICONDUCTOR DEFECT INSPECTION

Hamid K. Aghajan

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Abstract of the Disclosure

10 A method and associated apparatus for relating a
test image with a reference image in an automated image
processing system is disclosed. The test and reference
images are aligned. A two-dimensional scatter plot is
then created by plotting the gray level of a test image
pixel against the gray level of a corresponding
15 reference image pixel for each aligned pixel location.

m-7793 US 1/10

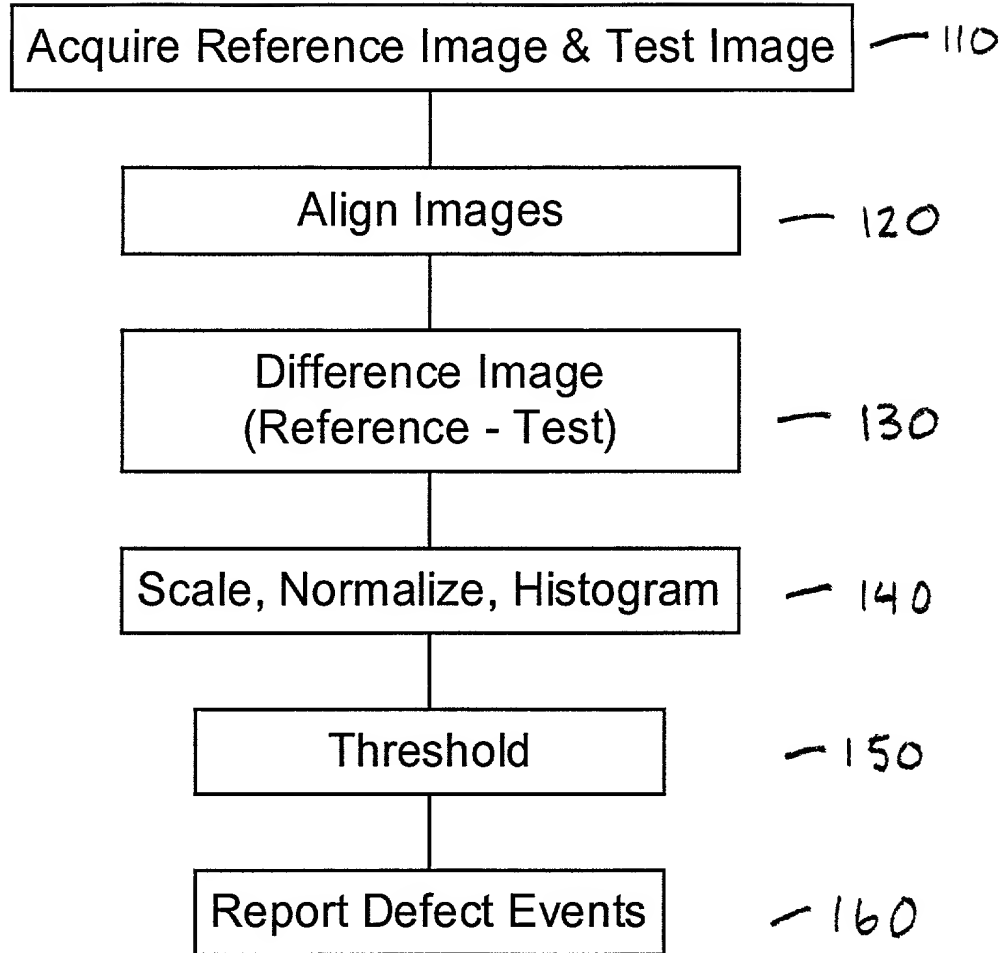


Fig. 1

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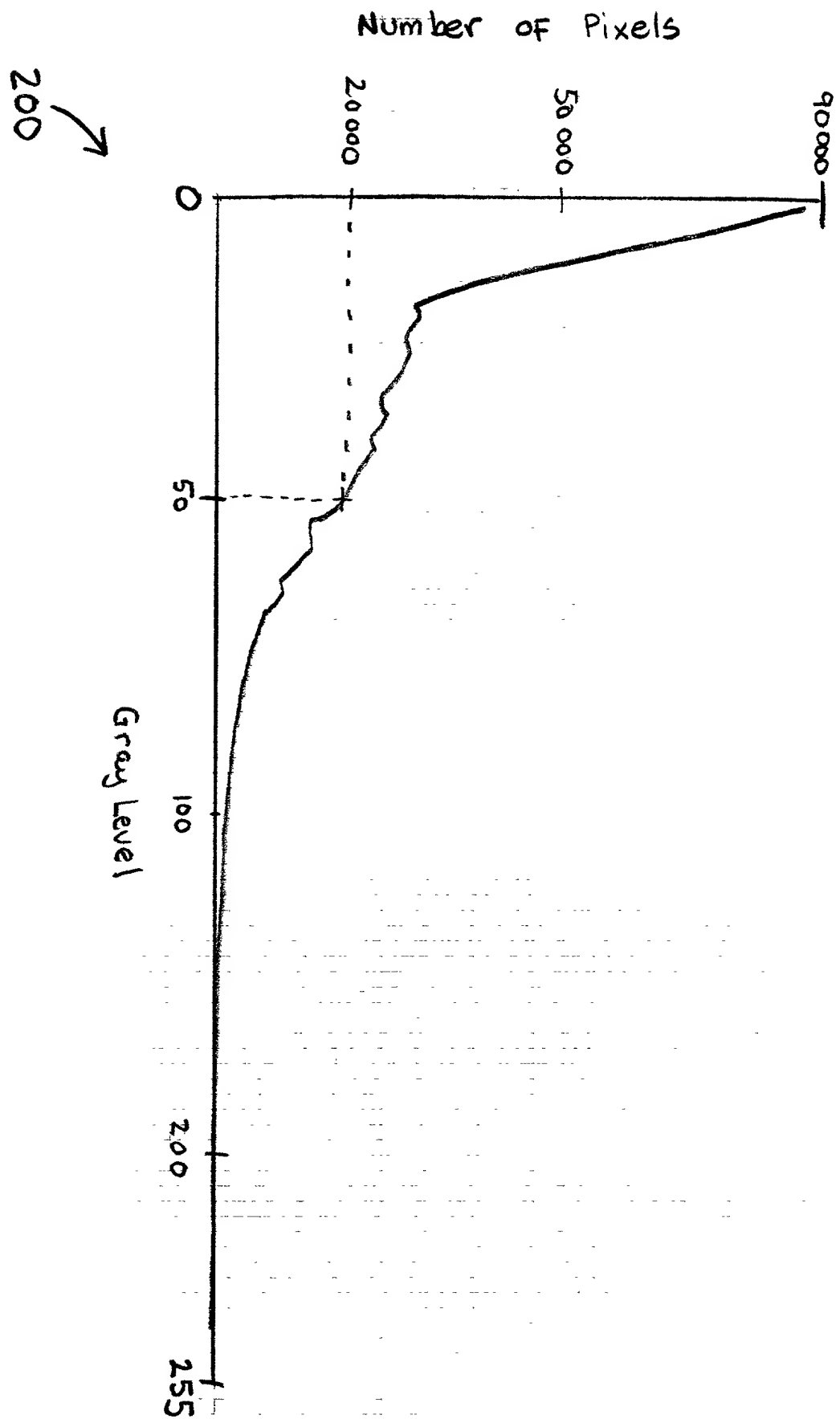


Fig. 2

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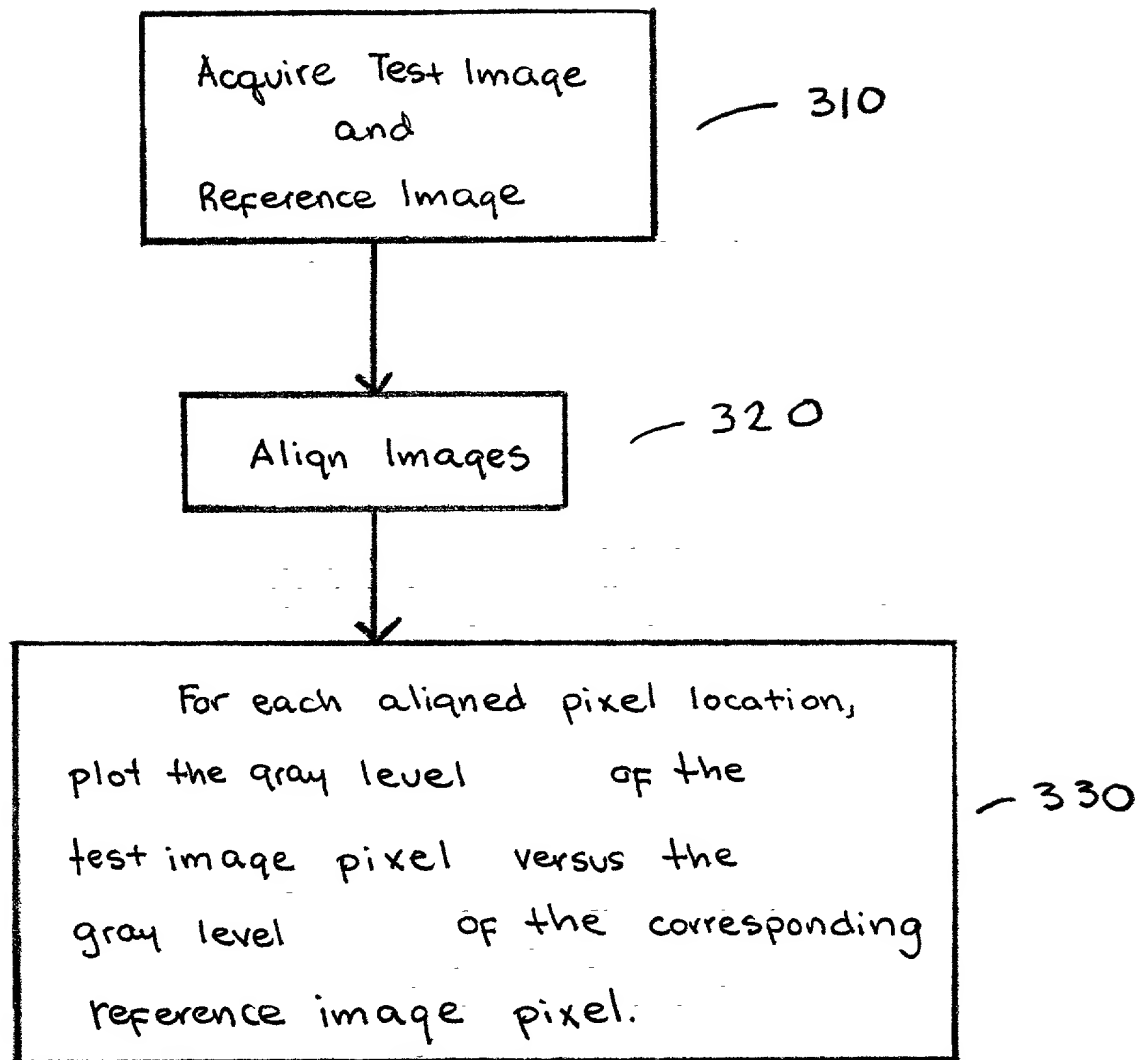


Fig 3

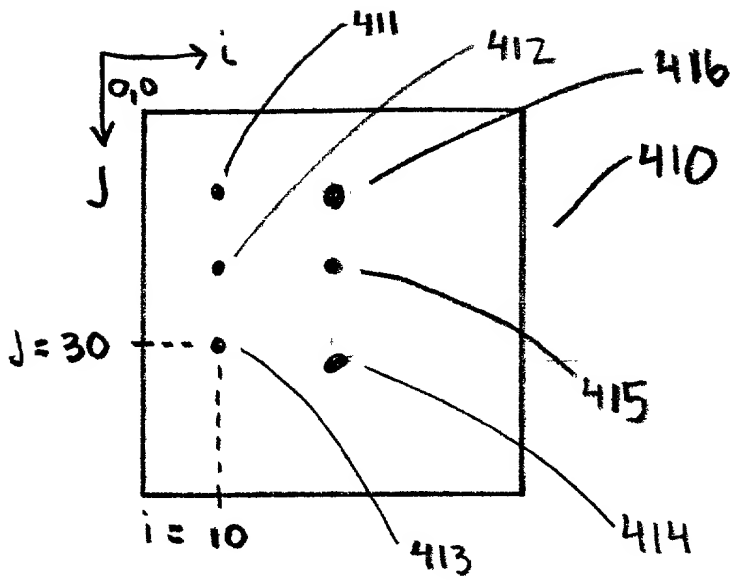


Fig. 4A

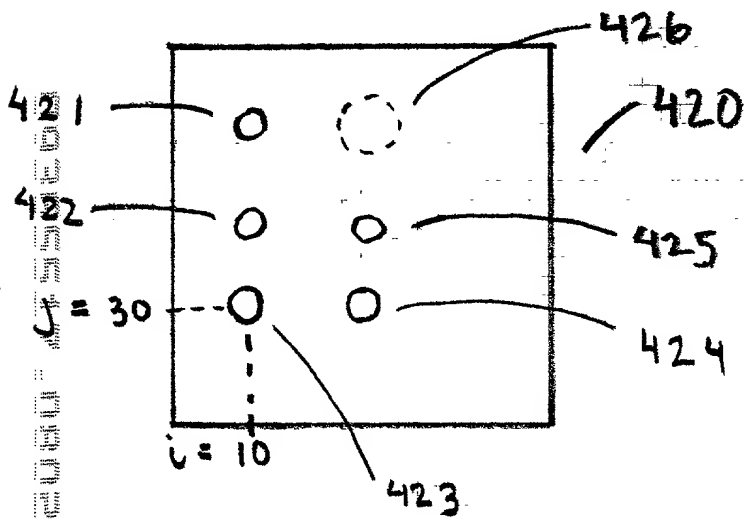


Fig. 4B

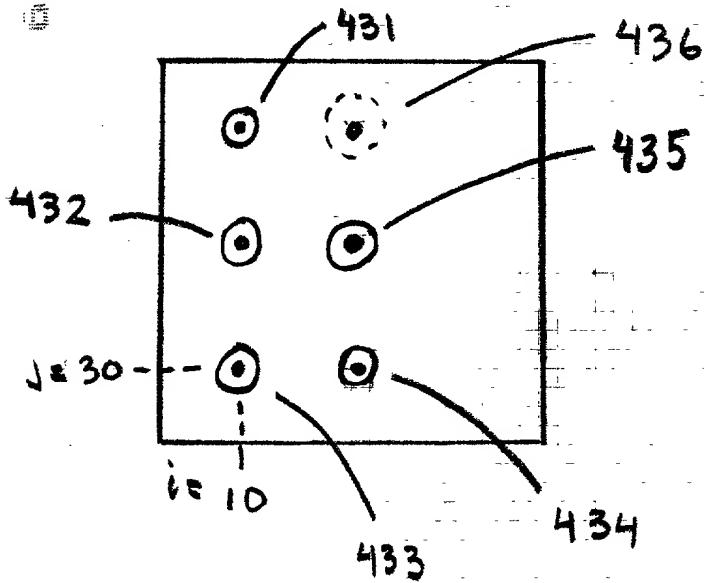


Fig. 4C

m-7793 us 5/10

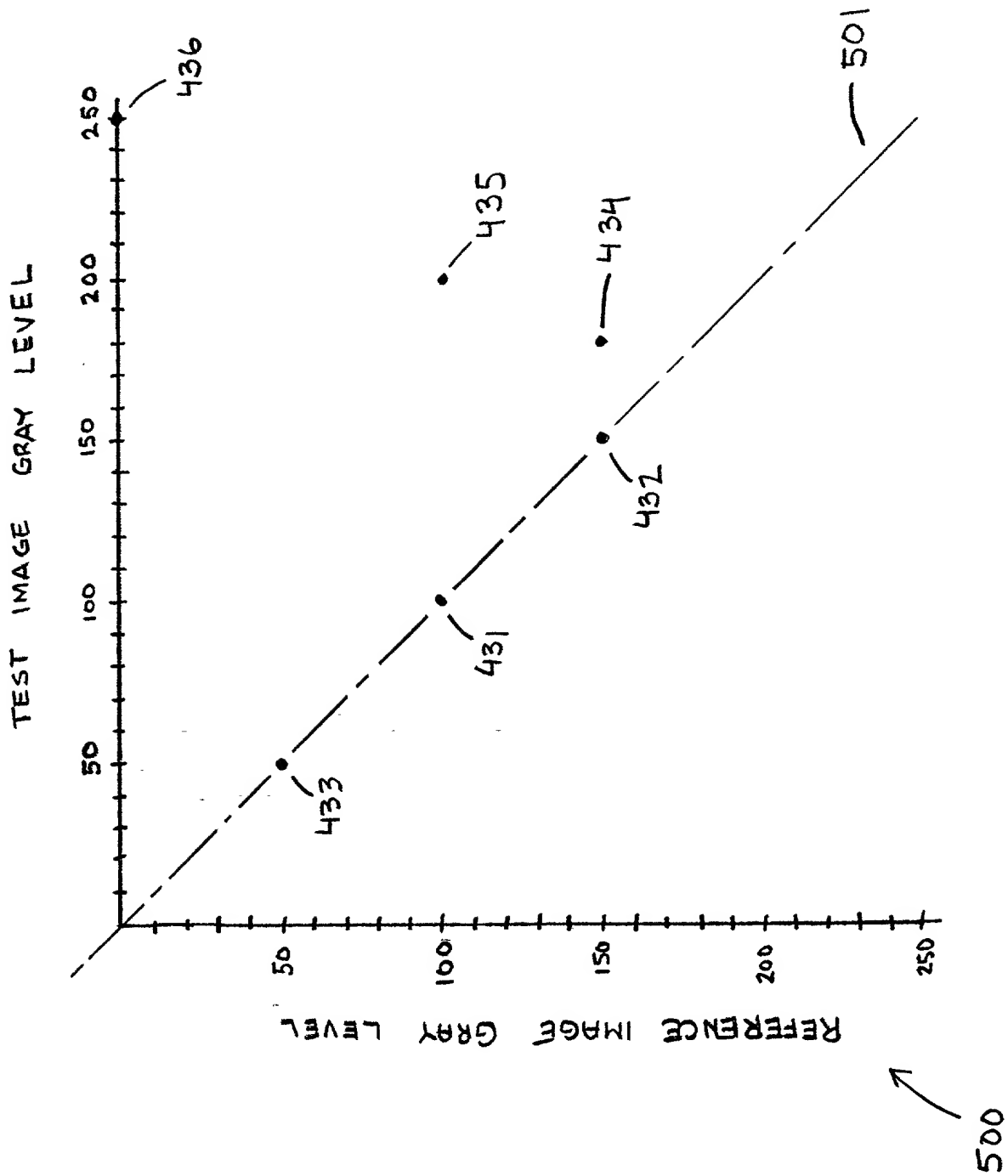


Fig 5A

M-7793 US 6/10

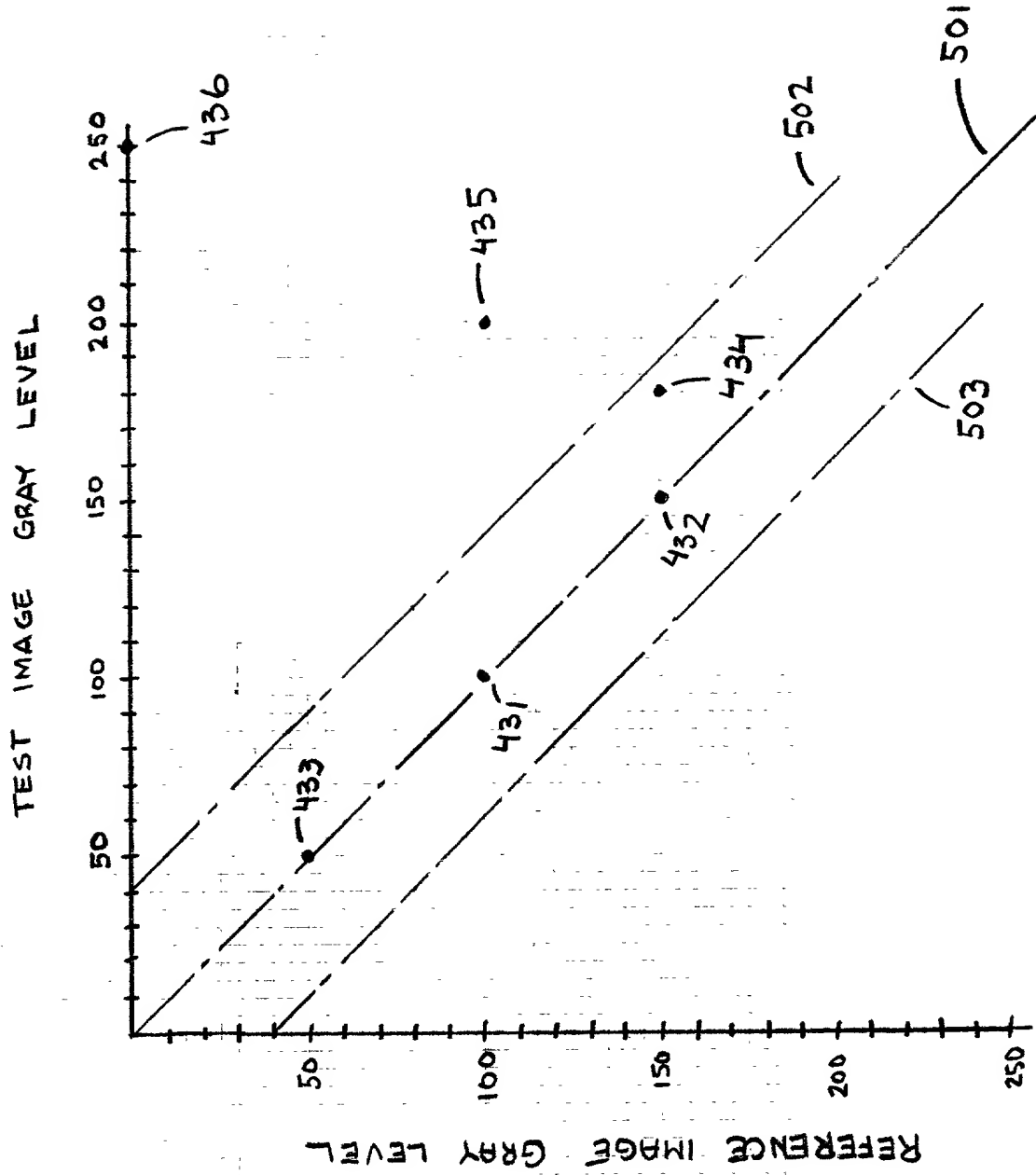


Fig 5B

500

M-7793 US 7/10

601

Defect

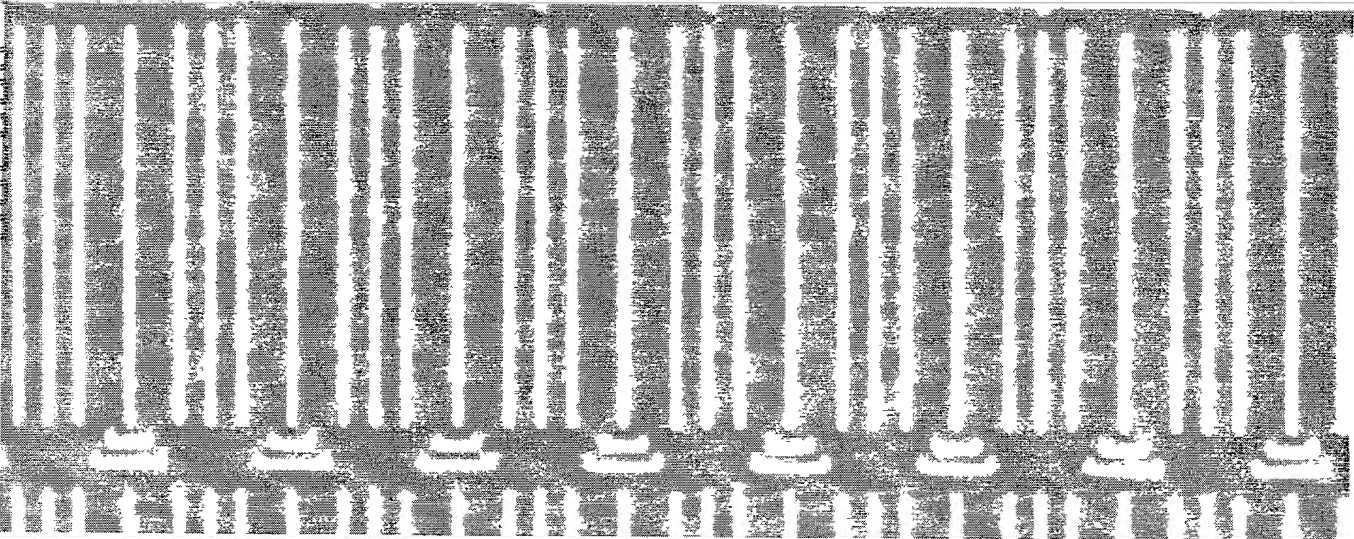
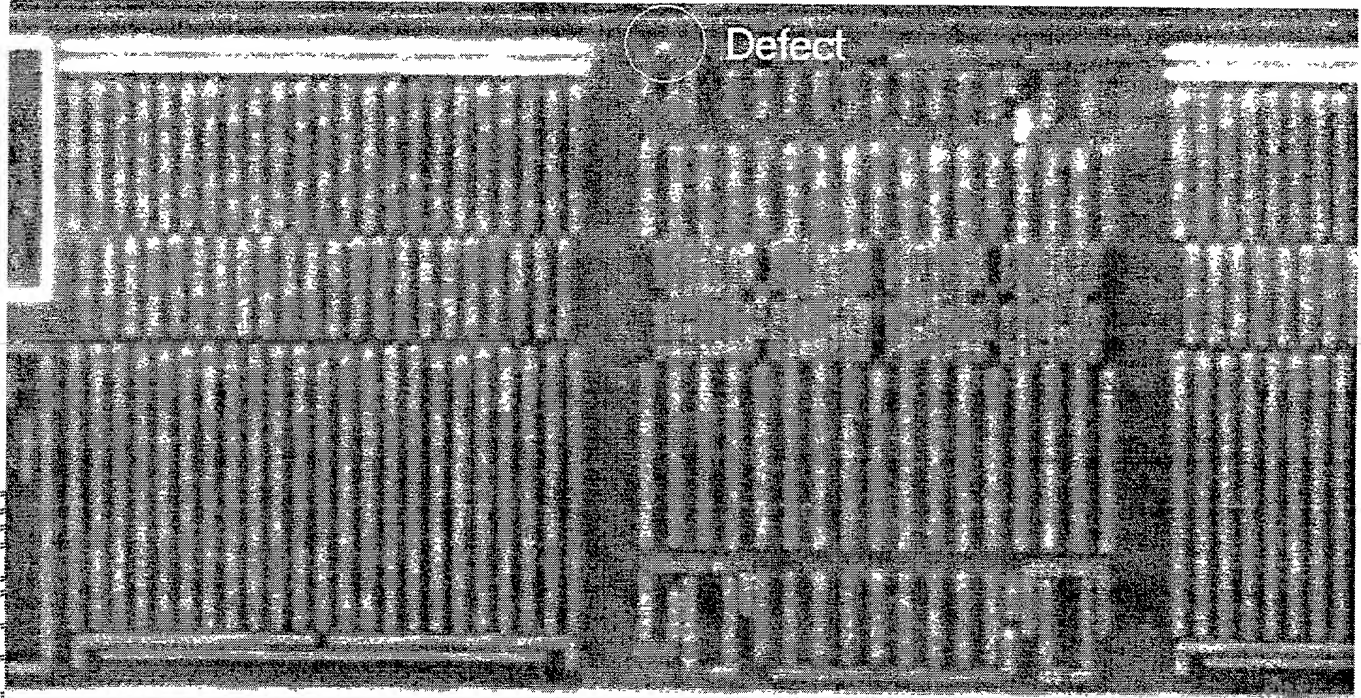
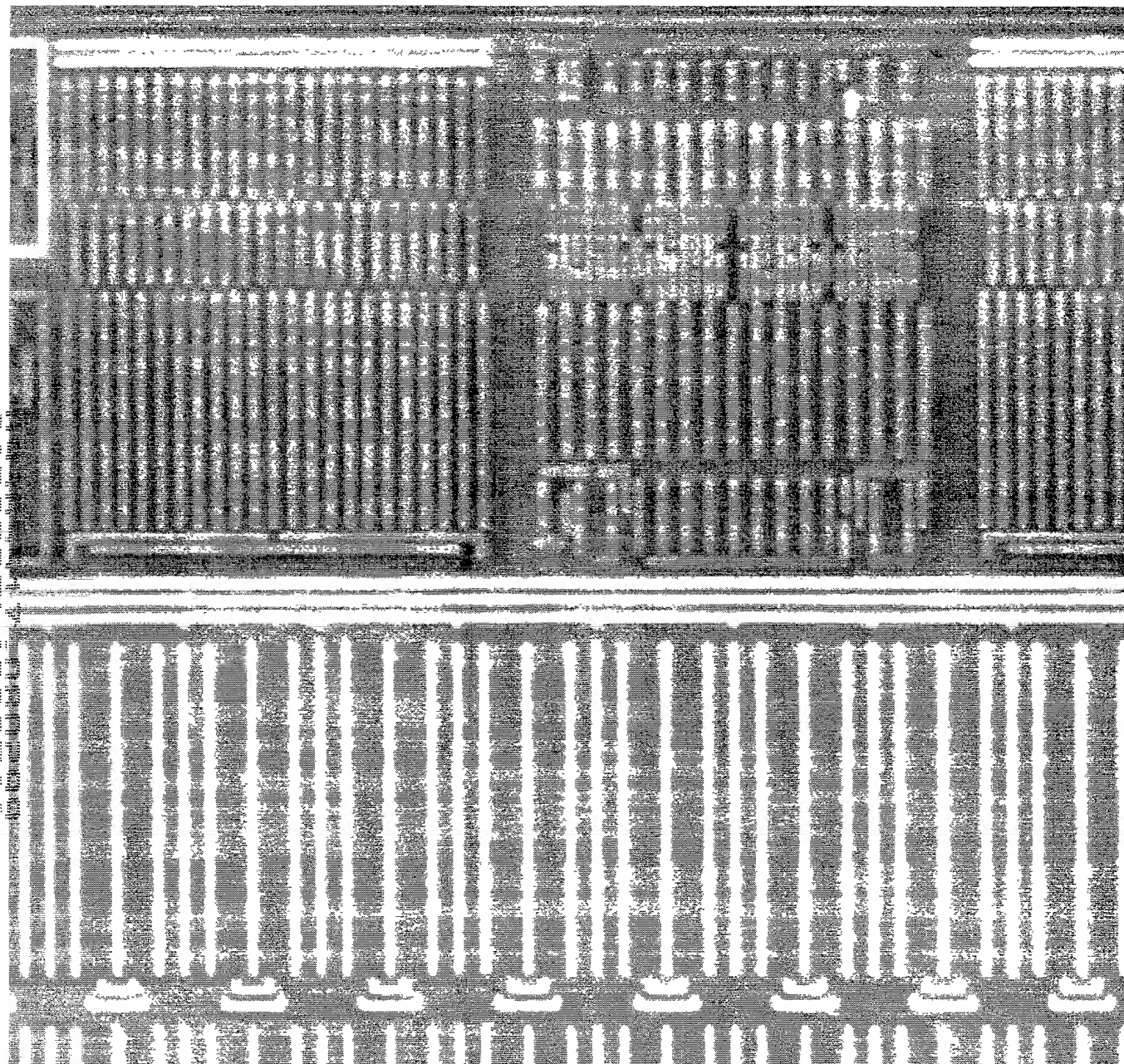


Fig. 6

m-7793 vs 8/10



↑

700

Fig. 7

111-7793 US 2/10



Fig. 8

M-7793 US 10/10

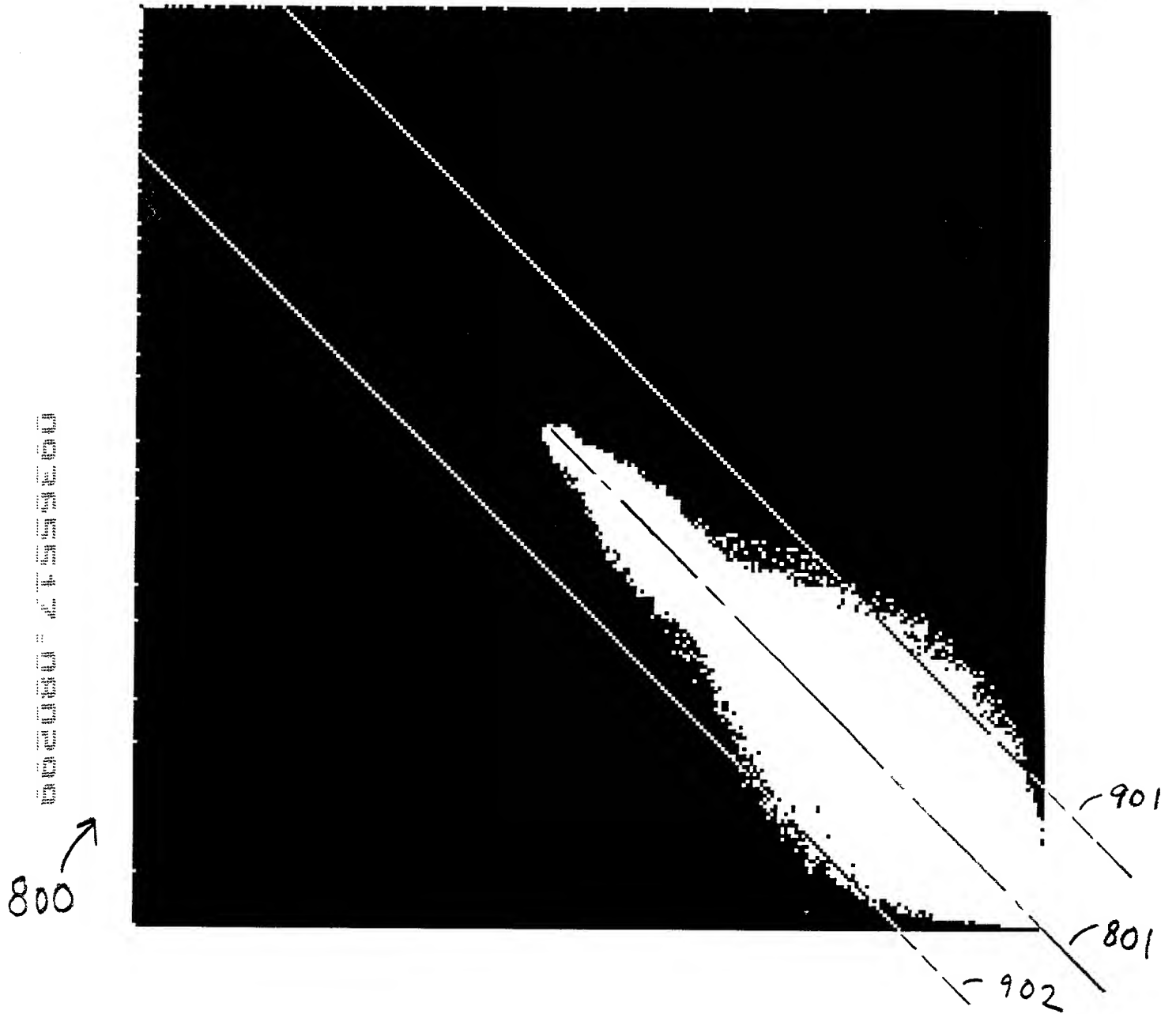


Fig. 9

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I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of subject matter (process, machine, manufacture, or composition of matter, or an improvement thereof) which is claimed and for which a patent is sought by way of the application entitled

Two-Dimensional Scatter Plot Technique For Defect Inspection

which (check) ☒ is attached hereto.

☐ and is amended by the Preliminary Amendment attached hereto.

☐ was filed on _____ as Application Serial No. _____

☐ and was amended on ____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information, which is material to patentability as defined in Title 37, Code of Federal Regulations, § 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, § 119(a)-(d) of any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America listed below and have also identified below any foreign application(s) for patent or inventor's certificate or any PCT international application(s) designating at least one country other than the United States of America filed by me on the same subject matter having a filing date before that of the application(s) of which priority is claimed:

Prior Foreign Application(s)			Priority Claimed	
Number	Country	Day/Month/Year Filed	Yes	No
N/A			<input type="checkbox"/>	<input type="checkbox"/>

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Provisional Application Number	Filing Date
N/A	

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Application Serial No.	Filing Date	Status (patented, pending, abandoned)
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